Department of Geodetic Science

DATA ANALYSIS IN CONNECTION WITH THE NATIONAL GEODETIC SATELLITE PROGRAM (II)

Fourth Semiannual Status Report

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The Ohio State University
Research Foundation
Columbus, Ohio 43212

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PREFACE

This project is under the supervision of Ivan I. Mueller, Professor of the Department of Geodetic Science at The Ohio State University, and it is under the technical direction of Jerome D. Rosenberg, Project Manager, Geodetic Satellites Program, NASA Headquarters, Washington, D.C. The contract is administered by the Office of University Affairs, NASA, Washington, D.C. 20546.

TABLE OF CONTENTS

Page

1. Statement of Work 1

2. Accomplishments During the Report Period 1

2.1 The North American GEOS-I Tracking Network 1

2.11 Geometric Adjustment 1

2.12 Short-Arc Orbital Mode Adjustment 11

2.2 The BC-4 Experiments 17

2.21 Experiments with the Adjustment of BC-4 Data in the Short-Arc and Geometric Modes 17

2.22 BC-4 Data Tape Processing 21

2.3 The SECOR Network in the Pacific Ocean 21

2.4 The Range-Difference Experiment 23

2.5 Conversion of Existing Computer Programs 26

3. Personnel 27

4. Travel 27

5. Reports Published to Date 28

1. STATEMENT OF WORK

The primary objective of the OSU investigation is the geometric analysis of geodetic satellite data. In order to fulfill this objective the following tasks are being attempted during the current grant period.

(1) Extension of the computer programs which can handle optical and/or range observations for range and range rate, Doppler, and laser systems.

(2) Development of data preprocessing systems to handle the data from the above observation methods.

(3) Analysis of observational data for the National Geodetic Satellite Program for the purpose of fulfilling the primary objective as observational data becomes available.

(4) The development of computer programs for the adjustment of optical, ranging and Doppler data in the short-arc mode.

(5) Theoretical investigations into sequential least squares adjustment of simultaneous satellite observations in combination with terrestrial data.

2. ACCOMPLISHMENTS DURING THE REPORT PERIOD

2.1 The North American GEOS-I Tracking Network

2.11 Geometric Adjustment

As mentioned in the last semiannual report, most of the simultaneous optical data (PC-1000, MOTS, and BC-4) that was deposited in the Data Center as of July 1, 1968, has been received. Since that time OSU has received from the U.S. Naval Observatory the new values for A.1 - UT1 and UT2 - UT1 for every day of the year from January 1, 1956 to September 20, 1967. These values made a significant difference in the UT1 times during the timespan of GEOS-I, and for this reason all times recorded on the data cards were converted

to what we have referred to as the "New UT1."

From the optical data available from the Data Center enough good data was available from 15 MOTS stations and 15 PC-1000 stations, all located in North America (see Fig. 2.1). This data, along with 2000 SECOR ranges from the SE United States, was used to perform four simultaneous network adjustments. These adjustments are referred to as NA-1, NA-2, NA-3, and NA-4. The characteristics of each of these adjustments is given below.

NA-1 Only MOTS and PC-1000 data was used. Columbia, Missouri was given a weight of 10 (which keeps the station coordinates effectively fixed). The scale was determined by imposing a chord constraint between Homestead, Fla. (3861) and Greenbelt, Md. (7043). These two stations were tied to the precise traverse of the Coast and Geodetic Survey. This chord distance was constrained to 1: 750,000 (as estimated by the USCGS).

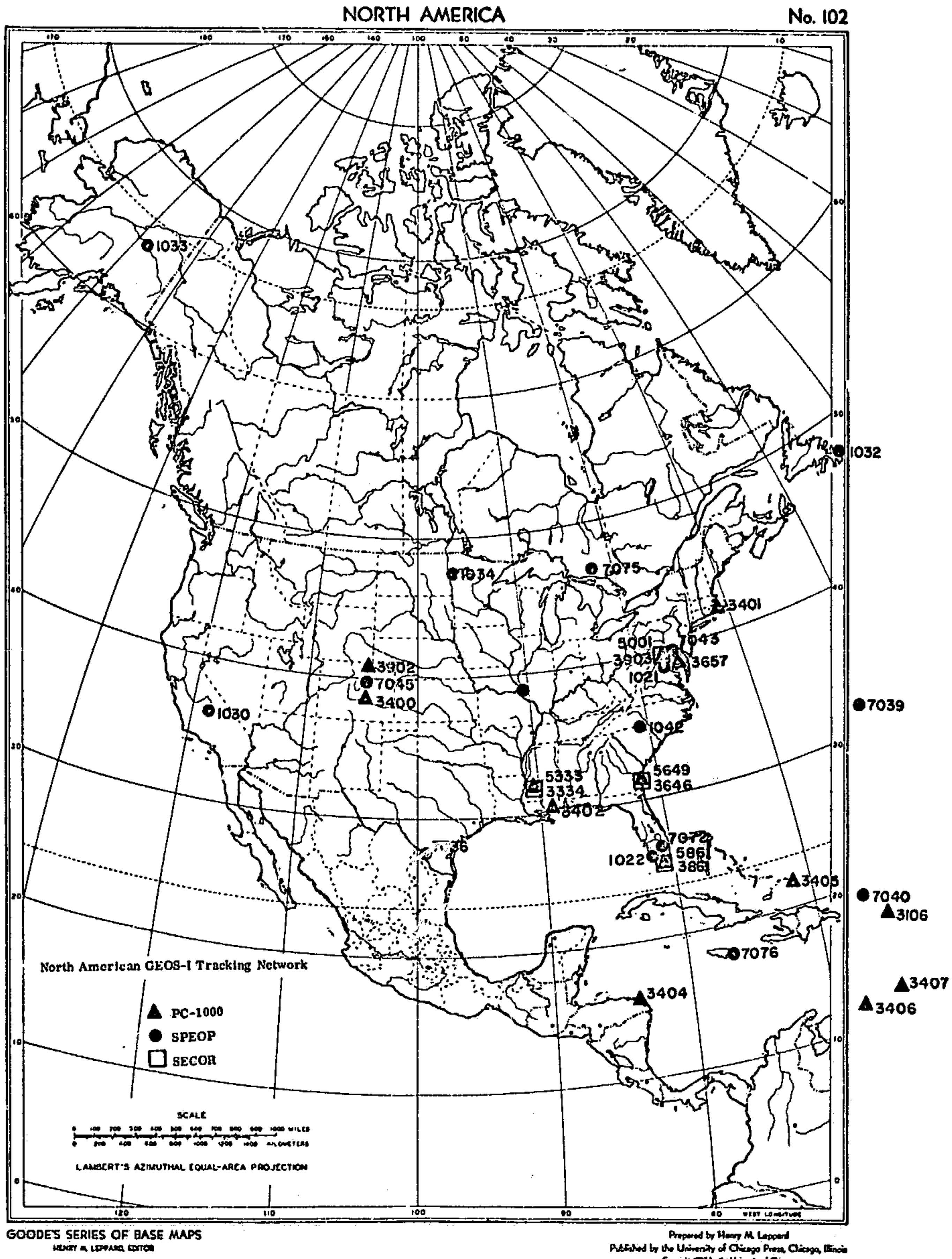
NA-2 Only MOTS and PC-1000 data was used. Columbia, Missouri was given a weight of 0.11 (which corresponds to the standard deviation computed by Simmons' formula). The scale was determined in the same way as the NA-1 adjustment

[illegible]

NA-3 The SECOR data was included in this adjustment along with the MOTS and PC-1000 data. Columbia, Missouri was given a weight of 0.11. There was no chord constraint; the scale was determined from the SECOR ranges.

NA-4 The SECOR data was included in this adjustment along with the MOTS and PC-1000 data. Columbia, Missouri was given a weight of 0.11. The scale was determined in the same way as in the NA-1 and NA-2 adjustments.

All of the information pertaining to these adjustments, along with the final adjusted coordinates, are given in Table 2.1. Also included in Table 2.2 are the North American datum transformation parameters.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North American GEOS-I Tracking Network
PC-1000
SPEOP
SECOR
SCALE
LAMBERT'S AZIMUTHAL EQUAL-AREA PROJECTION
GOODE'S SERIES OF BASE MAPS
HENRY M. LEPPARD, EDITOR
Prepared by Henry M. Leppard
Published by the University of Chicago Press, Chicago, Illinois

Fig. 2.1

Geodetic Coordinates of the North American GEOS-I Tracking Network

GOCC #	Name		NAD	σ	NA-1	σ	NA-2	σ	NA-3	σ	NA-4	σ
7075	Sudbury, Ontario	X	692646.1	6.0	0.7	4.8	0.7	5.6	- 12.9	8.1	- 1.1	7.0
	MOTS 40	Y	-4347225.8	5.0	9.6	5.8	9.6	6.4	- 5.4	8.3	2.1	7.9
		Z	4600298.3	4.9	8.6	5.0	8.6	5.8	0.7	7.7	10.7	6.8
1032	St. Johns, Newfoundland	X	2602802.5		-81.8	68.8	-81.8	68.8	-130.4	88.5	-89.2	87.4
	MOTS 40	Y	-3419301.2		-10.7	97.3	-10.7	97.4	- 50.4	124.1	-20.6	123.7
		Z	4697477.3		-43.8	37.8	-43.8	37.9	- 52.2	48.2	-41.3	48.0
3334	Greenville, Miss.	X	- 84957.5	4.1	10.3	15.8	10.3	16.1	- 17.2	8.9	- 1.8	7.1
	PC-1000	Y	-5328100.8	3.1	-13.0	13.0	-13.0	13.3	0.0	10.3	- 1.5	10.3
		Z	3493285.2	3.7	-38.9	10.4	-38.9	10.8	8.9	9.0	- 2.9	8.0
3902	Cheyenne, Wyo.	X	-1234668.8	2.9	39.2	31.7	39.2	31.9	56.8	40.6	44.7	40.4
	PC-1000	Y	-4651355.3	2.4	15.3	34.6	15.3	34.7	6.7	44.0	12.0	44.0
		Z	4174612.3	2.5	-40.2	11.5	-40.2	11.8	- 40.3	14.9	-36.6	14.8
1033	College, Alaska	X	-2299238.0	10.7	6.3	15.0	6.3	15.3	40.0	21.5	12.3	19.2
	MOTS 40	Y	-1445840.4	11.0	19.3	73.3	19.3	73.3	- 42.5	94.3	3.6	93.0
		Z	5751629.0	7.8	-20.1	40.0	-20.1	40.2	- 45.6	51.6	-20.5	50.9
3400	Colorado Springs, Colo.	X	-1275173.6	2.7	-21.5	15.5	-21.5	15.8	- 2.5	20.6	-16.8	20.0
	PC-1000	Y	-4798165.6	2.3	-21.1	11.6	-21.1	12.0	- 26.9	15.1	-25.3	15.1
		Z	3994037.6	2.4	7.0	8.0	7.0	8.5	10.3	10.5	12.5	10.4
3903	Herndon, Va.	X	1089023.7	6.4	- 7.3	11.6	- 7.3	11.9	- 21.0	11.0	- 4.7	9.4
	PC-1000	Y	-4843194.9	5.1	113.7	13.9	113.7	14.2	10.4	5.7	4.4	5.3
		Z	3991564.7	5.6	- 3.1	9.9	- 3.1	10.3	- 1.6	7.5	-13.7	6.2
7039	Bermuda Island	X	2308230.2	8.8	18.9	8.5	18.9	9.0	- 21.8	15.8	11.3	11.0
	MOTS 40	Y	-4873765.5	7.2	31.9	5.4	31.9	6.1	24.9	7.3	24.9	7.3
		Z	3394389.0	8.3	- 8.5	5.4	- 8.5	6.2	3.4	7.4	- 2.0	7.1

all units are in meters

Geodetic Coordinates of the North American GEOS-I Tracking Network

GOCC #	Name		NAD	σ	NA-1	σ	NA-2	σ	NA-3	σ	NA-4	σ
3405	Grand Turk	X	1919530.5	9.2	- 6.2	7.6	- 6.2	8.1	-40.0	13.8	-12.3	9.9
	PC-1000	Y	-5621245.2	6.6	27.8	5.8	27.8	6.5	32.9	8.4	23.9	7.8
		Z	2315617.1	9.0	-28.0	7.4	-28.0	8.0	2.0	11.5	-17.6	9.4
3407	Trinidad	X	2979925.0	11.4	- 5.3	11.4	- 5.3	11.7	-57.1	20.4	-15.3	14.4
	PC-1000	Y	-5513746.9	9.2	94.7	7.1	94.7	7.6	98.3	9.6	90.6	9.2
		Z	1180994.8	12.1	-25.1	12.0	-25.1	12.3	24.3	19.1	-10.1	14.9
3648	Hunter AFB, Ga	X	832594.6	6.3	2.8	5.1	2.8	5.9	-14.9	8.4	0.1	6.6
	PC-1000	Y	-5349690.7	4.6	17.5	4.9	17.5	5.7	12.7	4.7	5.5	4.0
		Z	3360414.7	5.7	- 1.2	5.3	- 1.2	6.0	15.9	6.1	3.8	4.4
3404	Swan Island	X	642541.2	8.5	-20.0	5.1	-20.0	5.9	-32.4	8.3	-21.4	7.4
	PC-1000	Y	-6054109.5	5.4	48.8	5.9	48.8	6.6	61.1	9.3	46.1	7.7
		Z	1895518.2	8.2	- 5.1	7.6	- 5.1	8.2	31.5	12.7	6.7	9.4
3657	Aberdeen, Md.	X	1186826.8	6.6	- 7.3	5.2	- 7.3	5.9	-28.7	9.6	-10.4	7.2
	PC-1000	Y	-4785340.8	5.3	20.8	5.2	20.8	6.0	11.8	7.1	14.0	7.0
		Z	4032705.0	5.7	4.3	4.0	4.3	4.9	6.1	5.6	8.9	5.5
3406	Curacao	X	2251837.6	10.7	- 1.0	8.2	- 1.0	8.7	-41.2	15.2	- 9.3	10.5
	PC-1000	Y	-5817069.3	7.8	24.5	5.8	24.5	6.5	32.5	8.7	20.5	7.6
		Z	1327016.0	11.0	11.8	10.1	11.8	10.5	58.6	16.7	26.4	12.4
7076	Jamaica, B.W.I.	X	1384188.1	9.1	4.0	6.5	4.0	7.1	-20.8	11.3	- 0.1	8.7
	MOTS 40	Y	-5905826.8	6.1	15.4	6.9	15.4	7.5	25.9	10.1	12.8	9.0
		Z	1966367.6	8.9	9.1	8.0	9.1	8.5	44.3	12.9	20.6	9.9
1021	Blossom Point, Md	X	1118061.3	6.5	- 7.3	5.0	- 7.3	5.8	-27.8	9.3	-10.3	7.1
	MOTS 40	Y	-4876472.4	5.1	20.9	4.4	20.9	5.2	13.8	6.1	14.6	6.1
		Z	3942793.7	5.6	0.0	3.9	0.0	4.8	3.1	5.4	4.9	5.4
3402	Semmes, Ala.	X	167291.0	5.2	- 1.3	4.0	- 1.3	4.9	- 5.9	6.4	- 1.1	6.1
	PC-1000	Y	-5482121.9	3.8	20.2	4.1	20.2	5.0	23.5	6.3	15.9	5.7
		Z	3244863.3	4.7	- 1.5	4.5	- 1.5	5.4	13.7	6.5	6.3	6.0

Geodetic Coordinates of the North American GEOS-I Tracking Network

GOCC #	Name		NAD	σ	NA-1	σ	NA-2	σ	NA-3	σ	NA-4	σ
3401	L. G. Hanscom Field, Mass.	X	1513184.2	7.4	-14.5	5.9	-14.5	6.6	-41.9	11.2	-19.4	8.0
	PC-1000	Y	-4463730.2	6.2	33.1	5.9	33.1	6.6	18.1	8.1	24.1	7.8
		Z	4282975.7	6.3	3.4	4.1	3.4	5.0	0.9	6.0	7.1	5.6
3106	Antigua Island	X	2881872.3	10.6	0.2	10.1	0.2	10.5	-50.0	18.9	- 9.5	12.7
	PC-1000	Y	-5372329.3	8.5	29.4	5.1	29.4	5.8	29.8	7.1	23.8	6.8
		Z	1868346.8	11.1	19.7	7.9	19.7	8.5	57.5	13.1	32.3	9.8
3861	Homestead AFB, Fla.	X	961792.0	7.4	8.6	4.6	8.6	5.5	- 6.9	8.2	7.4	6.5
	PC-1000	Y	-5679312.7	5.1	22.2	3.9	22.2	4.9	30.4	6.4	19.2	5.1
		Z	2729707.6	7.0	3.2	4.1	3.2	5.0	23.9	5.9	12.1	4.3
7040	San Juan, P. R.	X	2465090.5	10.1	- 2.6	8.7	- 2.6	9.2	-45.5	16.4	-10.6	11.1
	MOTS 40	Y	-5535082.5	7.7	15.5	5.1	15.5	5.9	19.0	7.4	11.0	6.8
		Z	1985346.2	10.3	- 4.1	7.1	- 4.1	7.7	31.4	12.1	7.7	8.8
7043	GSFC, Greenbelt, Md.	X	1130742.6	6.5	- 2.4	4.9	- 2.4	5.7	-21.8	9.4	- 3.6	7.0
	PTH-100	Y	-4831487.8	5.2	36.1	4.6	36.1	5.4	26.3	6.5	29.7	6.4
		Z	3993952.9	5.6	2.2	4.2	2.2	5.1	4.9	5.8	11.0	5.4
7045	Denver, Colo.	X	-1240449.5	2.6	12.1	5.2	12.1	6.0	28.9	8.8	15.2	7.5
	MOTS 40	Y	-4760379.7	2.2	1.4	4.2	1.4	5.1	- 7.3	6.2	- 4.9	6.2
		Z	4048804.6	2.4	7.1	4.2	7.1	5.1	7.8	6.0	10.6	5.9
1042	Rosman, N. C.	X	647539.6	5.5	- 9.8	3.8	- 9.8	4.8	-22.7	7.1	-11.6	5.9
	MOTS 40	Y	-5178083.5	4.2	14.7	3.3	14.7	4.4	12.6	5.1	9.3	5.0
		Z	3656534.4	4.9	- 1.6	3.7	- 1.6	4.7	6.1	5.2	4.1	5.2
7072	Jupiter, Fla.	X	976297.2	7.2	- 0.2	4.6	- 0.2	5.4	-18.0	8.5	- 2.7	6.6
	MOTS 40	Y	-5601549.2	5.0	13.1	4.1	13.1	5.1	18.4	6.5	9.0	5.7
		Z	2880071.8	6.7	- 2.1	4.5	- 2.1	5.4	18.2	7.1	6.2	5.8
7036	Edinburg, Tex.	X	- 828463.9	5.3	2.7	3.9	2.7	4.9	12.6	6.6	4.8	6.0
	MOTS 40	Y	-5657604.0	3.8	- 3.3	4.1	- 3.3	5.1	4.2	6.8	- 5.7	5.9
		Z	2816639.7	5.0	4.6	5.0	4.6	5.7	25.6	8.1	12.1	6.6

Geodetic Coordinates of the North American GEOS-I Tracking Network

GOCC #	Name		NAD	σ	NA-1	σ	NA-2	σ	NA-3	σ	NA-4	σ
1034	E. Grand Fork, Minn.	X	- 521678.9	4.3	2.3	3.0	2.3	4.2	8.4	5.5	4.0	5.3
	MOTS 40	Y	-4242198.1	3.7	1.1	4.2	1.1	5.1	-15.0	6.9	- 5.8	6.2
		Z	4718543.6	3.5	1.3	4.0	1.3	4.9	- 9.0	6.9	2.7	5.6
1030	Mojave, Calif.	X	-2357214.3	5.7	- 0.9	8.2	- 0.9	8.7	34.0	14.5	5.5	10.6
	MOTS 40	Y	-4646475.7	4.8	7.1	4.0	7.2	4.9	- 3.2	6.0	0.6	5.9
		Z	3668134.6	5.2	- 4.5	4.2	- 4.5	5.1	2.5	5.8	0.3	5.8
7037	Columbia, Mo.	X	- 191260.6	3.0	0.0	0.3	0.0	2.9	0.6	3.7	0.7	3.7
	MOTS 40	Y	-4967428.4	2.5	0.0	0.3	0.0	2.9	- 3.3	3.5	- 3.6	3.5
		Z	3983084.5	2.7	0.0	0.3	0.0	2.9	0.8	3.3	1.9	3.3
1022	Ft. Myers, Fla.	X	807883.1	7.3	2.0	3.9	2.0	4.8	-13.3	7.5	0.0	5.9
	MOTS 40	Y	-5652136.5	5.1	10.7	3.6	10.7	4.7	16.5	6.2	6.6	5.1
		Z	2833327.2	6.8	1.1	4.2	1.1	5.1	22.2	7.0	9.6	5.4
5861	Homestead, Fla.	X	963493.6	7.4					- 6.9	8.2	7.4	6.5
	SECOR	Y	-5679877.4	5.1					30.4	6.4	19.2	5.1
		Z	2727946.6	7.0					23.9	5.9	12.1	4.3
5001	Herndon, Va.	X	1088883.5	6.4					-21.0	11.0	- 4.7	9.4
	SECOR	Y	-4843079.7	5.1					10.4	5.7	4.4	5.3
		Z	3991674.3	5.6					- 1.6	7.5	-13.7	6.2
5333	Stoneville, Miss.	X	- 84975.8	4.1					-17.2	8.9	- 1.8	7.1
	SECOR	Y	-5328098.4	3.1					0.0	10.3	- 1.5	10.3
		Z	3493294.2	3.7					8.9	9.0	- 2.9	8.0
5649	Hunter AFB, Ga.	X	832512.0	6.3					-14.9	8.4	0.1	6.6
	SECOR	Y	-5349730.3	4.6					12.7	4.7	5.5	4.
		Z	3360369.8	5.7					15.9	6.1	3.8	4.4

General Information

	NA-1	NA-2	NA-3	NA-4
No. of PC-1000 stations	15	15	15	15
No. of SPEOP stations	15	15	15	15
No. of SECOR stations	—	--	4	4
σ (a priori)	2"	2"	2"	2"
Rejection criteria	6".3	6".3	optical: 6".3 range: 5 m	optical: 6".3 range: 5 m
Weight assigned to Columbia, Mo.	10	0.11	0.11	0.11
Chord constraint between Homestead and Greenbelt (1 531 562.9 m)	1:750,000	1:750,000	—	1:750,000
Relative positions of the 4 SECOR stations and the 4 collocated PC-1000 stations was constrained by adding 999 to the diagonal elements of the corresponding 3x3 matrices	—	—	X	X
No. of known and unknown ground stations	30	30	34	34
No. of unknown ground stations	29	29	33	33
No. of observations minus 3 times No. of events	4306	4306	5281	5281
No. of spatial chord equations	1	1	0	1
No. of unknowns in normal equations	87	87	99	99
No. of degrees of freedom	4220	4220	5182	5183
Quadratic sum of all the residuals (VPV)	3951.4	3951.4	7818.3	7825.8
Variance of unit weight	0.9	0.9	1.5	1.5
Standard deviation of unit weight	1.0	1.0	1.2	1.2

These parameters are the translations (Δx_o, Δy_o, Δz_o), rotations (θ_1, θ_2, θ_3 or $\overline{\theta}_1$, $\overline{\theta}_2$, $\overline{\theta}_3$), and scale changes (ϵ) from the North American coordinates (x, y, z) to the adjusted satellite coordinates (X, Y, Z). The values for Δx_o, Δy_o, Δz_o are the translations as defined by Veis and Molodensky; the values θ_1, θ_2, θ_3 are the rotations as defined by Veis; and $\overline{\theta}_1$, $\overline{\theta}_2$, $\overline{\theta}_3$ are the rotations as defined by Bursa and Molodensky. The following equations were used:

$$
\begin{aligned}
X = {} & x + \Delta x_o + \epsilon \Delta x \\
& + (\sin \varphi_o \Delta y - \cos\varphi_o \sin\lambda_o \Delta z)\, dA \\
& - \cos(\lambda_o \Delta z) d\mu - (\cos\varphi_o \Delta y + \sin\varphi_o \sin\lambda_o \Delta z) d\nu
\end{aligned}
$$

$$
\begin{aligned}
Y = {} & y + \Delta y_o + \epsilon \Delta y \\
& + (-\sin\varphi_o \Delta x + \cos\varphi_o \cos\lambda_o \Delta z)\, dA \\
& - (\sin\lambda_o \Delta z)\, d\mu + (\cos\varphi_o \Delta x + \sin\varphi_o \cos\lambda_o \Delta z)\, d\nu
\end{aligned}
$$

$$
\begin{aligned}
Z = {} & z + \Delta z_o + \epsilon \Delta z \\
& + (\cos\varphi_o \sin\lambda_o \Delta x - \cos\varphi_o \cos\lambda_o \Delta y)\, dA \\
& + (\cos\lambda_o \Delta x + \sin\lambda_o \Delta y)\, d\mu \\
& + (\sin\varphi_o \sin\lambda_o \Delta x - \sin\varphi_o \cos\lambda_o \Delta y)\, d\nu
\end{aligned}
$$

where

$dA = \theta_3$

$d\mu = \theta_2$

$d\nu = \theta_1$

φ_o = latitude of origin

λ_o = longitude of origin

for the Veis parameters;

and where

$dA = \overline{\theta}_3$

$d\mu = \overline{\theta}_2$

$d\nu = \overline{\theta}_1$

$\varphi_o = 0^\circ$

$\lambda_o = 90^\circ$

for the Bursa and Molodensky parameters.

$\Delta x, \Delta y, \Delta z$	are the coordinate differences between the station in question and the origin (at φ_o, λ_o in the Veis and Molodensky cases, and at the origin of the coordinate system in the Bursa case)

The NA-2 solution is considered the most reliable. From Table 2.2 it is evident that while the translations are not significant, a systematic 1" rotation in azimuth (to the east) and a 1."3 rotation in the prime vertical plane (to the west) is present between the NAD system and the satellite-determined system. It is also interesting to note the scale change indicated in solutions NA-3 and NA-4.

Table 2.2

Datum Transformation Parameters

Parameter	NA-1	σ	NA-2	σ	NA-3	σ	NA-4	σ
Δx_o(m)	0.6	2.0	0.4	2.3	7.9	2.7	2.6	2.6
Δy_o(m)	2.4	1.7	4.1	2.1	-1.9	2.4	-1.3	2.3
Δz_o(m)	0.6	1.7	-0.3	2.0	2.0	2.3	3.5	2.2
θ_3 (")	-1.0	0.3	-1.0	0.3	-0.9	0.3	-0.8	0.3
θ_2 (")	-0.2	0.4	0.0	0.4	-0.1	0.5	0.0	0.5
θ_1 (")	1.4	0.3	1.3	0.3	1.1	0.3	1.0	0.3
$\overline{\theta}_3$ (")	-1.7	0.3	-1.7	0.3	-1.4	0.3	-1.3	0.3
$\overline{\theta}_2$ (")	-0.1	0.3	-0.1	0.3	0.0	0.3	-0.0	0.3
$\overline{\theta}_1$ (")	-0.2	0.4	0.0	0.4	-0.1	0.5	-0.0	0.5
ϵ ($\times 10^{-6}$)	-1.7	1.4	-1.6	1.6	-17.0	1.8	-4.6	1.7

2.12 Short-Arc Orbital Mode Adjustment

In addition to the geometric solutions described in section 2.11, one adjustment was performed in the short-arc mode. Only the optical tracking stations were involved in this adjustment since no timing information was available for the SECOR observations. The results of this adjustment are given in Table 2.3.

The orbital arcs used in the short-arc adjustment were limited to about 10^m. These arcs are too short to afford a strong determination of the scale of the network through the adopted value of the GM. Therefore, scale was furnished by constraining the spatial chord distance between Homestead, Florida, and Greenbelt, Maryland, as had been done in the geometric adjustments. This distance and its a priori uncertainty were computed again from the geodetic coordinates of these two stations on the Cape Canaveral datum (i.e., the USCGS high-precision traverse).

The geocentric coordinates of Columbia, Missouri were constrained in order to define the origin of the coordinate system. These geocentric coordinates together with their associated covariance matrix, were taken from [Kurt Lambeck, "A Spatial Triangulation Solution for a Global Network and the Position of the North American Datum Within It," presented at the Annual Meeting of the AGU, April, 1969]. Lambeck's geocentric coordinates for Columbia are

$$X = -191\ 290\,\text{m} \pm 3.8$$
$$Y = 4967\ 274\,\text{m} \pm 4.1$$
$$Z = 3983\ 255\,\text{m} \pm 4.1$$

The difference between the NAD coordinates and the short-arc solution coordinates of Columbia was (NAD - short arc)

$$\Delta x = 32.1\ \text{m}$$
$$\Delta y = -158.8\ \text{m}$$
$$\Delta z = -171.3\ \text{m}$$

In order to be able to compare the short-arc solution coordinates to the NAD coordinates, these shifts were added to the short-arc solution. The resulting coordinate differences appear under the heading "Orbital" in Table 2. 3. The uncertainty of these coordinates was obtained by quadratically removing the uncertainties of the Lambeck geocentric coordinates (3.8, 4.1, 4.1) of Columbia from the standard deviations of the short-arc solution, and quadratically adding the uncertainties of the NAD coordinates of Columbia (3.0, 2.5, 2.7).

The geometric mode adjustment that most nearly resembles the orbital mode adjustment in terms of data used and constraints applied is the one designated NA-2. The short-arc solution and the standard deviation between the two was computed by removing the variance of the coordinates of Columbia from the variances of the two solutions and adding the resulting variances. These also appear in Table 2.3.

From the following table it is evident that the agreement between the geometric adjustment and the short-arc adjustment is satisfactory at all stations, except at St. Johns, Newfoundland, and especially at College, Alaska, where the blame should probably be placed on the insufficient amount of data available and/or on the poor geometry.

Table 2.3

Coordinates of GEOS-I Optical Tracking Stations from the Short-Arc Orbital Mode Adjustment

GOCC#	Name		NAD	Orbital	σ	Orbital - NA-2	σ
7075	Sudbury, Ontario	X	692 646.1	5.5	6.1	4.8	7.1
	MOTS 40	Y	-4347 225.8	13.7	6.1	4.1	8.2
		Z	4600 298.3	14.0	5.4	5.4	6.9
1032	St. Johns, Newfoundland	X	2602 802.5	170.4	87.4	252.2	111.1
	MOTS 40	Y	-3419 301.2	621.9	275.1	632.6	291.8
		Z	4697 477.3	-475.6	231.2	431.8	234.2
1033	College, Alaska	X	-2299 238.0	94.1	24.5	87.8	28.6
	MOTS 40	Y	-1445 840.4	820.0	31.5	800.7	79.7
		Z	5751 629.0	-546.3	51.0	-526.2	64.7
3903	Herndon, Va.	X	1689 023.7	- 13.8	13.8	- 6.5	17.7
	PC-1000	Y	-4843 194.9	94.5	16.1	- 19.2	21.2
		Z	3991 564.7	13.8	11.6	16.9	15.0
7039	Bermuda	X	2308 230.2	16.9	11.7	- 2.0	14.1
	MOTS 40	Y	-4873 765.5	31.7	6.1	- 0.2	7.9
		Z	3394 389.0	- 3.4	6.3	5.1	8.0
3405	Grand Turk	X	1919 530.5	- 30.8	10.9	- 24.6	12.9
	PC-1000	Y	-5621 245.2	9.5	8.0	- 18.3	9.7
		Z	2315 617.1	7.4	11.1	- 20.6	13.1
3407	Trinidad	X	2979 925.0	- 50.2	17.1	- 46.9	20.4
	PC-1000	Y	-5513 746.9	100.0	10.5	5.3	12.5
		Z	1180 994.8	3.9	18.4	29.0	21.8

all units are in meters

Coordinates of GEOS-I Optical Tracking Stations from the Short-Arc Orbital Mode Adjustment

GOCC#	Name		NAD	Orbital	σ	Orbital - NA-2	σ
3648	Hunter AFB, Ga.	X	832 594.6	4.9	6.9	2.1	8.0
	PC-1000	Y	-5349 690.7	7.7	6.2	- 9.8	7.6
		Z	3360 414.7	3.2	4.9	7.1	8.5
3404	Swan Island	X	642 541.2	-17.9	8.2	2.1	9.2
	PC-1000	Y	-6054 109.5	45.3	8.8	- 3.5	10.4
		Z	1895 518.2	26.9	11.8	32.0	13.4
3657	Aberdeen, Md.	X	1186 826.8	- 7.4	7.6	- 0.1	8.6
	PC-1000	Y	-4785 340.8	19.1	8.5	1.7	9.8
		Z	4032 705.0	5.8	6.1	1.5	6.8
3406	Curacao	X	2251 837.6	-22.7	11.8	-21.7	14.1
	PC-1000	Y	-5817 069.3	37.0	9.0	12.5	10.6
		Z	1327 016.0	28.1	15.6	16.3	18.4
7076	Jamaica, B.W.I.	X	1384 188.1	-17.1	8.8	-21.1	10.4
	MOTS 40	Y	-5905 826.8	- 1.8	8.3	-17.2	10.6
		Z	1966 367.6	31.7	10.3	22.6	12.8
1021	Blosson Point, Md.	X	1118 061.3	-17.3	7.5	-10.0	8.5
	MOTS 40	Y	-4876 472.4	9.4	5.5	-11.5	6.7
		Z	3942 793.7	6.6	5.0	6.6	5.8
3402	Semmes, Ala.	X	167 291.0	- 8.0	6.5	- 6.7	7.0
	PC-1000	Y	-5482 121.0	20.2	6.2	0.0	7.1
		Z	3244 863.3	-10.0	7.6	8.5	8.5

Coordinates of GEOS-I Optical Tracking Stations from the Short-Arc Orbital Mode Adjustment

GOCC #	Name		NAD	Orbital	σ	Orbital - NA-2	σ
3401	L. G. Hanscom Field, Mass.	X	1513 184.2	-28.7	8.9	-14.3	10.2
	PC-1000	Y	-4463 730.2	5.8	9.5	-27.3	11.0
		Z	4282 875.7	21.3	6.2	17.9	7.0
3016	Antigua Island	X	2881 872.3	-27.1	15.9	-27.3	18.6
	PC-1000	Y	-5372 329.3	26.5	11.4	- 2.9	12.3
		Z	1868 346.8	56.2	14.9	36.5	16.7
3861	Homestead AFB, Fla.	X	961 792.9	12.2	6.9	3.6	7.7
	PC-1000	Y	-5679 312.7	11.9	5.6	-10.3	6.6
		Z	2729 707.6	9.4	6.1	6.2	7.0
7040	San Juan, P.R.	X	2465 090.5	-43.8	12.4	-41.2	14.8
	MOTS 40	Y	-5535 082.5	- 9.7	6.5	-25.2	8.1
		Z	1985 346.2	36.2	10.2	40.3	12.2
7043	GSFC, Greenbelt, Md.	X	1130 742.6	7.8	7.1	10.2	8.0
	PTH-100	Y	-4831 487.8	46.4	6.3	10.3	7.6
		Z	3993 952.9	- 5.9	6.1	8.1	7.0
7045	Denver, Colo.	X	-1240 449.5	- 2.8	6.4	-14.9	7.7
	MOTS 40	Y	-4760 379.7	10.2	5.0	8.8	6.2
		Z	4048 804.6	7.6	5.6	0.5	6.5
1042	Rosman, N.C.	X	647 539.6	- 2.1	6.2	7.7	6.6
	MOTS 40	Y	-5178 083.5	21.6	4.6	6.9	5.3
		Z	3656 534.4	-12.4	5.5	-10.8	6.1

Coordinates of GEOS-I Optical Tracking Stations from the Short-Arc Orbital Mode Adjustment

GOCC #	Name		NAD	Orbital	σ	Orbital - NA-2	σ
7072	Jupiter, Fla.	X	976 297.2	-16.4	6.5	-16.2	7.3
	MOTS 40	Y	-5601 549.2	-11.7	5.0	-24.8	6.2
		Z	2880 071.8	-11.7	6.4	- 9.6	7.5
7036	Edinburg, Tex.	X	- 828 463.9	- 6.4	5.1	- 9.1	5.7
	MOTS 40	Y	-5657 604.0	-11.3	5.7	- 8.0	6.8
		Z	2816 639.7	5.6	7.2	1.0	8.4
1034	E. Grand Forks, Minn.	X	- 521 678.9	- 2.9	4.2	- 5.2	4.2
	MOTS 40	Y	-4242 198.1	11.6	5.4	10.5	6.5
		Z	4718 543.6	7.4	5.1	6.1	6.0
1030	Mohave, Calif.	X	-2357 214.3	-35.6	10.2	-34.7	12.7
	MOTS 40	Y	-4646 475.7	15.1	5.0	8.0	6.1
		Z	3668 134.6	-15.7	5.8	-11.3	6.7
7037	Columbia, Mo.	X	- 191 260.6	0.0	3.0	0.0	0.0
	MOTS 40	Y	-4967 428.4	0.0	2.5	0.0	0.0
		Z	3983 084.5	0.0	2.7	0.0	0.0
1022	Ft. Myers, Fla.	X	807 883.1	4.9	5.8	2.9	6.2
	MOTS 40	Y	-5652 136.5	2.6	4.9	- 8.1	5.8
		Z	2833 327.2	7.4	6.4	6.3	7.3

General Information:	No. of unknown stations	30
	No. of observations	6247
	No. of orbital arcs	86
	Degrees of freedom	5641
	Standard deviation of the observation of unit weight	1.0

The chord distance between Homestead, Fla., and Greenbelt, Md., as obtained from their Cape Canaveral Datum coordinates (USCGS high precision traverse) was constrained to one part in 750,000.

2.2 The BC-4 Experiments

2.21 Experiments with the Adjustment of BC-4 Data in the Short-Arc and Geometric Modes

Previous experiments with the adjustment of BC-4 data were reported in the last semiannual report (p. 3) and in [Ohio State University Department of Geodetic Science Report No. 118]. These experiments used data from the following four BC-4 stations:

6001	Thule, Greenland
6002	Beltsville, Maryland
6003	Moses Lake, Washington
6038	Revilla Gigedo Island, Mexico

The first series of experiments used 12 plates and the second series used 45 plates. Five adjustments were performed in each series: 20 individual images from each plate were adjusted in both the short-arc and geometric modes; 10 individual images per plate were adjusted in both the short-arc and geometric modes; and a single fictitious image per plate, analogous to the ESSA fictitious image, was adjusted in the geometric mode. From these experiments it appeared that the most information could be obtained by processing 20 individual images per plate in either the short-arc or geometric mode, although some allowance must be made for the worsening of the solution if the correlation between different images on the same plate is neglected. The way in which the data was selected appeared to have at least as great an effect on the solution as the mode in which the data was processed.

During this report period two more series of experiments were carried out, each consisting of the same five adjustments. These were:

(1) The Minimal Data Set series, consisting of 9 plates and 5 events. If only one image per plate is used, this number of plates and events gives a unique (i.e., not overdetermined) solution with zero degrees of freedom. Thus

this is the minimum number of plates and events for which a solution for the network may be obtained. The results of this series of experiments are shown in Table 2.4.

(2) The 74 Plate Data Set series, which utilized all of the acceptable data available from the four stations. The results of this series of experiments are shown in Table 2.5.

The minimal data set series was conducted to investigate the strength of a solution using as little data as possible. In comparison with solutions obtained from larger data sets, the minimal data set solutions are unacceptably weak. Not only are the a posteriori uncertainties of the adjusted coordinates high, but there are also very large differences between the different adjustments. There are several coordinates for which the difference between two solutions is several times the standard deviation of that difference, suggesting that with such a small set of data the solution is highly affected by sampling variations as well as any small components of systematic error remaining in the observations.

In the case of the 45 plate series, the agreement between different solutions was much better, although there were a few coordinates for which different solutions differed by more than would be expected from an examination of their standard deviations. The 74 plate series of adjustments was carried out in order to see if closer agreement would be obtained between the different solutions if more data were used. The results of this series indicate that this is indeed so.

The results of the 74 plate series indicate that the use of several images per plate is clearly superior to the use of a single fictitious image per plate. Even when all acceptable data available is used, the use of the single fictitious image produced only about 1/4 degree of freedom per unknown, which does not appear to be a sufficient overdeterminancy to produce reliable results.

It may be the case that the use of a single fictitious image will produce good results when an even larger set of data is available, or when global networks, such as the U.S. World Geometric Satellite Net being established

Table 2.4

Minimal Data Set Experiments
9 Plates, 5 Events

Experiment	Moses Lake X	Moses Lake Y	Moses Lake Z	Revilla Gigedo X	Revilla Gigedo Y	Revilla Gigedo Z	Thule X	Thule Y	Thule Z	Degrees of freedom	A posteriori stan. dev. of a single obs.
	-2127800 m +	-3785800 m +	4656000 m +	-2160900 m +	-5642700 m +	2035300 m +	546500 m +	-1390000 m +	6180200 m +		
1. Orbital mode 10 ind. images	+15.7 (10.6)	+150.1 (50.7)	-152.3 (34.5)	-21.4 (18.2)	+214.3 (45.6)	-183.5 (54.5)	-159.0 (31.5)	-13.3 (29.8)	-177.7 (49.6)	240	1".8
2. Orbital mode 20 ind. images	+34.5 (13.9)	+163.5 (70.7)	-70.0 (46.6)	-1.7 (17.8)	+197.1 (58.4)	-103.4 (69.2)	-87.6 (47.1)	17.0 (25.7)	-201.5 (84.7)	506	1.8
3. Geometric mode 10 ind. images	-21.5 (17.1)	-44.2 (88.8)	-18.1 (62.0)	-55.5 (21.5)	+70.5 (73.9)	-29.4 (91.3)	+1.0 (61.8)	-37.7 (34.6)	-87.3 (110.1)	66	1.8
4. Geometric Mode 20 ind. images	-23.6 (13.0)	-64.1 (66.0)	+3.4 (45.5)	-52.2 (16.5)	+36.4 (55.1)	+24.3 (67.1)	+43.6 (45.7)	-4.1 (25.6)	+1.5 (80.9)	138	1.8
5. 1 fictitious image Geometric Mode	-31.3 [22.5]	-111.3 [117.7]	+39.9 [[illegible]]	-67.5 [27.7]	-50.6 [97.3]	+127.9 [118.5]	+63.5 [80.9]	-45.4 [41.4]	+39.8 [142.3]	0	0.7

Beltsville is held fixed on the SAO C-5 datum. The first row of each entry gives the adjusted coordinate, and the second row gives the standard deviation.

Table 2.5

74 Plate Data Set

Experiment	Moses Lake X -2127800 m +	Moses Lake Y -3785800 m +	Moses Lake Z 4656000 m +	Revilla Gigedo X -2160900 m +	Revilla Gigedo Y -5642700 m +	Revilla Gigedo Z 2035300 m +	Thule X 546500 m +	Thule Y -1390000 m +	Thule Z 6180200 m +	Degrees of freedom	A posteriori stand. dev. of single obs.
1. Orbital Mode 20 ind. images	-24.4 (2.1)	-81.2 (6.9)	27.0 (6.0)	-62.0 (5.4)	- 0.5 (8.1)	81.4 (9.3)	57.3 (6.1)	-16.9 (9.0)	- 8.4 (10.9)	2278	1".6
2. Orbital Mode 10 ind. images	-24.7 (2.7)	-81.5 (9.1)	25.2 (8.0)	-56.2 (7.2)	- 4.6 (11.0)	86.5 (12.9)	65.4 (8.2)	- 7.5 (11.4)	-10.1 (14.9)	1106	1.6
3. Geometric Mode 20 ind. images	-24.6 (3.6)	-77.9 (7.5)	20.2 (6.5)	-64.5 (6.8)	+ 3.7 (9.1)	66.0 (10.4)	45.0 (6.8)	-23.1 (10.0)	-34.0 (12.1)	601	1.7
4. Geometric Mode 10 ind. images	-24.3 (4.0)	-77.3 (10.4)	20.7 (9.1)	-55.6 (8.7)	- 1.7 (12.7)	69.5 (14.7)	59.9 (9.3)	- 7.6 (13.3)	-17.1 (16.9)	306	1.7
5. Geometric Mode 1 fictitious image	-27.8 (5.6)	-90.5 (17.8)	23.9 (13.9)	-64.6 (12.3)	-35.9 (18.5)	85.9 (22.1)	65.3 (15.0)	-28.5 (19.8)	+29.8 (26.0)	23	0.8

Beltsville is held fixed on the SAO C-5 datum. The first row of each entry gives the adjusted coordinate, and the second row gives the standard deviation.

by the USCGS, are considered. However, it appears quite clear that at least for small networks, the best results are obtained by using several images per plate, such as 10 or 20, and adjusting in either the geometric or the short-arc mode.

2.22 BC-4 Data Tape Processing

This work concerned the magnetic tape Astro #221 (Serial #3380) which was deposited with the NSSDC by ESSA on April 15, 1968, and which contains approximately 75,000 BC-4 observations on 298 files (plates). The details of the work were described in the last semiannual report. Essentially three tasks were involved:

(1) Bad and duplicated plates were deleted.

(2) Corrections for parallactic refraction, phase angle, and light travel time were made to all observations so that the corrected observations represent truly geometric directions to the center of the satellite at the recorded time.

(3) The tape was unblocked and put into card image format so that it can be read by standard Fortran programs. After unblocking, the data occupied three reels of tape.

All work on this phase was completed during the reporting period. The three reels of magnetic tape, together with a description of their contents, were sent to the NSSDC on March 27, 1969.

2.3 The SECOR Network in the Pacific Ocean

The investigation involving the SECOR data from the Pacific network is in its final stages. There was only enough 4-station simultaneous data available from the 9 stations extending from Truk Island to Midway, and this investigation consisted of tying these stations together in one coordinate system using both goemetric and short-arc adjustments. Because of the lack of known coordinates and orientation in this network, arbitrary station constraints had

to be imposed. However, the same constraints were imposed on both the geometric and short-arc adjustments as a means of comparing the results. A separate report on this investigation will be published shortly.

An interesting by-product of the SECOR investigation was the modifications that were made to the short-arc computer program. Changes were made so that the orbital elements $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$ in either the earth-fixed or inertial system can be used if they are available. Another very significant modification was to allow for an error model term for each observing station on each pass to be carried as an unknown. If a priori information about zero set of ambiguity level is available this can also be included in the adjustment.

2.4 The Range-Difference Experiment

In order to verify the theory and the formulas when using range differences as observed quantities, five programs will be used in this sequence:

(1) data generating program

(2) range differences forming program

(3) coefficients program

(4) repunching program

(5) adjustment programs, using the method of least squares, namely (a) method or variation of parameters, (b) modifying the solution by the constraints.

The data generating program uses Keplerian orbit to represent the motion of a satellite in short-arc method. The system of reference is the true celestial system which is, for this purpose, assumed motionless. Keplerian orbit is represented by a set of six parameters (ω, r, i, e, $\overline{M}_e$, $\overline{M}_1$). The semi-major axis is computed by

$$a = \sqrt[3]{\frac{k^2 M}{\overline{n}^2}}$$

where

$$\overline{n} = \overline{M}_1$$

These parameters may be supplemented by additional "osculating" parameters, namely ω_1, r_1, e_1, $\overline{M}_2$. For given times the program computes, among other things, the ground stations' coordinates in A. T. system using their geodetic coordinates, the coordinates of the satellite in A. T. system and also the ranges from the ground stations to the satellite.

Ranges from all ground stations (fixed and unfixed) to all satellite positions serve as an input to the range differences forming program, together with stipulated standard deviations in the case when the observations have random errors attached to them. This program forms the range differences corresponding to previously generated satellite positions, either errorless or with

attached errors.

Using range differences as observed quantities, ground stations' coordinates in A. T. system (coordinates of fixed ground stations and approximate coordinates of unknown or weighed ground stations) and approximate coordinates of satellite positions in A. T. system, the nonzero coefficients in observation equations and the constant terms are computed by the coefficients program.

If the geometry is supplemented by the short-arc method, the six Keplerian parameters (or eventually ten parameters) are used in eliminating satellite position parameters during one pass so that the number of parameters is reduced. In such a case, the program also computes nonzero coefficients for the constraint equations accounting for this elimination, using as additional input approximate values of the orbital parameters.

The repunching program puts the above-computed coefficients and constant terms in appropriate places in corresponding matrices for an adjustment.

For the short-arc method two ways are possible: (1) Make an adjustment by "A" method for orbital parameters and unfixed ground station coordinates. (2) For the case when purely geometric adjustment was already carried out for satellite positions and ground station coordinates, take advantage of this solution and modify it by using the method of constraints. This is accomplished by adjustment programs, mentioned at the beginning.

For generated data all five steps are used consecutively. For real data computations start at step (3) (i. e. , coefficients program).

It is possible to weigh all or part of the parameters (ground station coordinates, orbital parameters, or satellite position coordinates). Also constraints amoung ground stations may be incorporated and computations carried out by the program mentioned in steps (5) and (6).

Over the period of the last several months the first four programs were written while the adjustment programs had been written and tested before.

During many of the testing runs with generated data some difficulties were encountered, first using the geometry alone. The observation equations for range differences correspond to those of ranges when differences between the consecutive observation equations are made and used instead. This amounts to a loss of information pertaining to absolute position of one satellite position, say the first. To compensate for the loss of this vital information, another kind of information is needed. If, for instance, the range from some or all ground stations to the first satellite position is known (with certain precision), the above-mentioned information is provided for and the system is equivalent to the range case: actually the observation equations for ranges may be restored knowing the observation equation for the first satellite position and observation equations for the following range differences.

Another possibility is to have more ground stations fixed (or weighed) than would be necessary for the range case. Failing to do this leads to ill-conditioned systems invalidating all the results.

It is being currently examined how many such stations are needed and what causes eventual ill-conditioning which appears to be more serious than was foreseen. It has been found so far that the minimum number of known ground stations in three-dimensional space yielding a valid solution in some cases is 5, while in a plane it is 3. It also appears that for a valid solution for unknown ground stations, the number of passes should be at least two (in which case it would be best if they intersected in right angles).

It is proposed that the study of the range difference adjustment continue so as to lead to a general conclusion and analysis pertaining to a minimum number of known ground stations needed for the range difference model using both geometric and short-arc modes, and analysis of the precision and applications of this model.

2.5 Conversion of Existing Computer Programs

As mentioned in the last semiannual report, The Ohio State University Computer Center has recently installed an IBM 360/75 computer. Although the date of its removal is not decided, it is expected that OSU's 7094 computer will be removed sometime in the next year. This means that all computer programs written under this contract must be converted to the 360 operating system and Fortran IV language. For programs that were originally written in Fortran IV for the 7094 the conversion is not difficult. However, the programs that were originally written in the SCATRAN language must be rewritten.

During this report period the program known as "optical program" was rewritten for the 360/75. This program forms normal equations from simultaneous satellite directions, such as furnished by BC-4, MOTS, and PC-1000 cameras. During the conversion, the features described in the last semiannual report were incorporated into the program. In addition, the following features were added to the data editing module to gain greater flexibility.

(1) The rejection test was modified so that a single observation can be deleted from the event, and the rest of the event may be used. Previously the whole event was deleted whenever a blunder was detected in the data.

(2) A rejection test based on the geometric quality of the individual event was added. The need for a test of this kind became apparent during the adjustments of the GEOS-I North American Optical Network described in section 2.1. This network contained five tracking stations, all employing different cameras, located in close proximity at Jupiter, Florida. At times, events made up only of observations from cameras at Jupiter appear in the data. Since these events produce satellite position determinations that are geometrically extremely weak, it is necessary to detect and delete them.

The new optical program was fully debugged during the report period and is now operational.

3. PERSONNEL

Ivan I. Mueller, Project Supervisor, part time

Georges Blaha, Research Associate, part time

Charles R. Schwarz, Research Associate, part time

James P. Reilly, Research Assistant, part time

Irene B. Tesfai, Technical Assistant, full time

William H. Wright, Research Aide, part time

4. TRAVEL

Trips made by project personnel during the report period are:

Ivan I. Mueller
Washington, D. C., March 12-13, 1969
To attend meeting of the American Congress on Surveying and Mapping-American Society of Photogrammetry

Ivan I. Mueller
Washington, D. C., April 21-25, 1969
To attend Annual Meeting of the American Geophysical Union

Charles Reed Schwarz
Washington, D. C., April 24-25, 1969
To attend two sessions of the Annual Meeting of the American Geophysical Union

Ivan I. Mueller
Paris, France and London, England, February 20 - March 3, 1969
To attend meeting of the International Commission for Artificial Satellites, International Association of Geodesy in Paris; to visit the computer center of the Western European Sub-Commission at Feltham, Middlesex.

5. REPORTS PUBLISHED TO DATE

OSU Department of Geodetic Science Reports published under Grant No. NSR 36-008-003:

70 The Determination and Distribution of Precise Time
by Hans D. Preuss
April, 1966

71 Proposed Optical Network for the National Geodetic Satellite Program
by Ivan I. Mueller
May, 1966

82 Preprocessing Optical Satellite Observations
by Frank D. Hotter
April, 1967

86 Least Squares Adjustment of Satellite Observations for Simultaneous Directions or Ranges, Part 1 of 3: Formulation of Equations
by Edward J. Krakiwsky and Allen J. Pope
September, 1967

87 Least Squares Adjustment of Satellite Observations for Simultaneous Directions or Ranges, Part 2 of 3: Computer Programs
by Edward J. Krakiwsky, George Blaha, Jack M. Ferrier
August, 1968

88 Least Squares Adjustment of Satellite Observations for Simultaneous Directions or Ranges, Part 3 of 3: Subroutines
by Edward J. Krakiwsky, Jack Ferrier, James P. Reilly
December, 1967

93 Data Analysis in Connection with the National Geodetic Satellite Program
by Ivan I. Mueller
November, 1967

OSU Department of Geodetic Science Reports published under Grant No. NGR 36-008-093:

100 Preprocessing Electronic Satellite Observations
by Joseph Gross
March, 1968

106 Comparison of Astrometric and Photogrammetric Plate Reduction Techniques for a Wild BC-4 Camera
by Daniel H. Hornbarger
March, 1968

110 Investigations into the Utilization of Passive Satellite Observational Data
by James P. Veach
June, 1968

114 Sequential Least Squares Adjustment of Satellite Triangulation and Trilateration in Combination with Terrestrial Data
by Edward J. Krakiwsky
October, 1968

118 The Use of Short Arc Orbital Constraints in the Adjustment of Geodetic Satellite Data
by Charles R. Schwarz
December, 1968